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TECHNICAL NOTE
D-1203

FORCES AND MOMENTS ON SPHERE-CONE BODIES IN NEWTONIAN FLOW

By Robert R. Dickey

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Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

The static longitudinal aerodynamic characteristics of a family of sphere-cone combinations (fineness ratios from 1.0 to 6.0) were computed by means of Newtonian impact theory. The effects of angle of attack, fineness ratio, and center-of-gravity location are shown. The results indicate that, with the center of gravity at or near the center of volume, the sphere-cone combinations are statically stable at trim points that provide low to moderate lift-drag ratios. In general, the lift-drag ratio increased with increasing fineness ratio. As an example, with the center of gravity at the center of volume, the lift-drag ratio at trim was increased from approximately 0.05 to 0.56 by increasing the fineness ratio from 1.2 to 6.0.

INTRODUCTION

Consideration of the heating, deceleration, guidance, and stability problems encountered during high-speed entry into the earth's atmosphere indicates that it would be desirable for an entry vehicle to have a blunt forward face and to be statically stable at a trim point which would provide a moderate lift-drag ratio. It would also be desirable for the launch configuration to have axial symmetry. Preliminary analysis indicated that a simple body of revolution consisting of a sphere with a converging conical afterbody possesses these desirable characteristics and, consequently, that such shapes merit further investigation. An analytical study utilizing Newtonian impact theory was therefore undertaken to gain further knowledge of the static aerodynamic characteristics of sphere-cone combinations. The purpose of this report is to present the results of that study. The effects of angle of attack, fineness ratio, and center of gravity on the lift, drag, and pitching-moment characteristics of a family of sphere-cone combinations having fineness ratios from 1.0 to 6.0 are shown.

NOTATION

A	axial force
C_A	axial-force coefficient, $\frac{A}{qS}$
C_A'	local axial-force coefficient per unit length, $\frac{dC_A}{d(x/d)}$
C_D	drag-force coefficient, $C_A \cos \alpha + C_N \sin \alpha$
C_L	lift-force coefficient, $C_N \cos \alpha - C_A \sin \alpha$
C_m	pitching-moment coefficient, $\frac{m}{qSd}$
C_m'	local pitching-moment coefficient per unit length, $\frac{dC_m}{d(x/d)}$
C_N	normal-force coefficient, $\frac{N}{qS}$
C_N'	local normal-force coefficient per unit length, $\frac{dC_N}{d(x/d)}$
C_p	pressure coefficient
D	drag force
d	diameter of the sphere
e	distance of the center of gravity from the longitudinal axis
F.R.	fineness ratio of the sphere-cone combination, $\frac{l}{d}$
L	lift force
$\frac{L}{D}$	lift-drag ratio
l	length of the sphere-cone combination
m	pitching moment about the center of gravity
N	normal force (force perpendicular to the longitudinal axis measured in the α plane)
q	free-stream dynamic pressure
R	radius of the sphere
r	local cross-sectional radius of the sphere-cone combination
S	frontal area of the sphere, πR^2

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x distance along the longitudinal axis from the nose of the sphere-cone combination

x_o distance along the longitudinal axis from the nose to the center of gravity of the sphere-cone combination

α angle of attack (angle between the longitudinal axis and the free-stream velocity vector)

β radial angle measured in a plane normal to the longitudinal axis (See fig. 1.)

A586

β_u radial angle denoting the upper limit of the body surface exposed to the air stream (See fig. 1.)

δ local body slope with respect to the longitudinal axis (See fig. 1.)

η angle between the free-stream velocity vector and the perpendicular to the local surface of the body

SPHERE-CONE COMBINATIONS

The geometry of the family of sphere-cone combinations considered in this report is shown in figure 1. Each combination consisted of a sphere with a converging conical afterbody tangent to the sphere. The length of the conical afterbody relative to the diameter of the sphere was varied so that the resultant fineness ratios of the sphere-cone combinations ranged from 1.0 to 6.0.

METHOD

In order to obtain the total force and moment coefficients of a sphere-cone combination, it is convenient to determine first the local force coefficients acting on a transverse section. The general expressions for the local axial-force and normal-force coefficients per unit length of an arbitrary body of revolution are given in reference 1 as

$$C_A' = \frac{4r}{\pi R} \tan \delta \int_{-\pi/2}^{\beta_u} C_p d\beta \qquad (1)$$

and

$$C_N' = -\frac{4r}{\pi R}\int_{-\pi/2}^{\beta_u} C_p \sin \beta \, d\beta \tag{2}$$

The foregoing equations are for that portion of the body exposed to the air stream. In the analysis the portion of the body shielded from the air stream is assumed to have a pressure coefficient of zero and therefore not to contribute to the body forces.

The pressure coefficient, C_p, of a surface exposed to the air stream is given by Newtonian theory as

$$C_p = 2 \cos^2\eta \tag{3}$$

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where, for an arbitrary body of revolution

$$\cos \eta = \cos \alpha \sin \delta - \sin \alpha \cos \delta \sin \beta \tag{4}$$

Substituting equations (3) and (4) into equations (1) and (2) and integrating yields

$$\begin{aligned} C_A' = \frac{4r}{\pi R} \tan \delta \Bigg[\left(\beta_u + \frac{\pi}{2}\right) (2 \cos^2\alpha \sin^2\delta + \sin^2\alpha \cos^2\delta) \\ + \cos \beta_u(\sin 2\alpha \sin 2\delta - \sin^2\alpha \cos^2\delta \sin \beta_u)\Bigg] \end{aligned} \tag{5}$$

and

$$\begin{aligned} C_N' = \frac{4r}{\pi R} \Bigg\{\frac{1}{2}\left(\beta_u + \frac{\pi}{2}\right) \sin 2\alpha \sin 2\delta + \cos \beta_u \Bigg[2 \cos^2\alpha \sin^2\delta \\ - \frac{1}{2} \sin 2\alpha \sin 2\delta \sin \beta_u + \frac{2}{3} \sin^2\alpha \cos^2\delta(\sin^2\beta_u + 2)\Bigg]\Bigg\} \end{aligned} \tag{6}$$

The local pitching-moment coefficient per unit length can be expressed in terms of the local geometric parameters and the local axial- and normal-force coefficients as

$$C_m' = \left(\frac{x_o}{d} - \frac{x}{d}\right) C_N' - \frac{r}{d} \tan \delta \, C_N' - \frac{e}{d} C_A' \tag{7}$$

The total axial-force, normal-force, and pitching-moment coefficients presented in this report were obtained by graphically integrating the corresponding local force and moment coefficients per unit length (determined from eqs. (5), (6), and (7)) over the total length of the configuration as indicated below:

$$C_A = \int_0^{l/d} C_A' d(x/d) \tag{8}$$

$$C_N = \int_0^{l/d} C_N' d(x/d) \tag{9}$$

$$C_m = \int_0^{l/d} C_m' d(x/d) \tag{10}$$

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RESULTS

The static longitudinal aerodynamic characteristics of a family of sphere-cone combinations, with the center of gravity located at the center of volume, are presented in figures 2 to 8. The results show that these blunt-faced bodies of revolution are statically stable at trim points that provide low to moderate lift-drag ratios. In general, for a given angle of attack, an increase in the fineness ratio results in an increase in the lift and drag coefficients and in the lift-drag ratio.

The trimmed ($C_m = 0$) aerodynamic characteristics of sphere-cone combinations, with center of gravity at the center of volume, are plotted as a function of the fineness ratio in figure 9. The results show that increasing the fineness ratio from 1.2 to 6.0 decreased the trim angle from approximately 79° to 31° and increased the lift-drag ratio from approximately 0.05 to 0.56. It should be noted that because of the rotational symmetry of the sphere-cone combinations, the trim angles may be considered as angles in pitch or yaw or any vector combination thereof. In order to direct the lift force in the desired direction, some auxiliary method of control (such as reaction jets) would be required for positioning and maintaining the configuration in the proper attitude of roll, pitch, and yaw. If, however, the rotational symmetry of the configuration is removed by locating the center of gravity off the longitudinal axis, the lift force could be placed in the desired direction by controlling only the roll attitude of the vehicle.

The effect of center-of-gravity location on the pitching-moment coefficients of a representative sphere-cone combination (fineness ratio = 2) is shown in figure 10 for the complete 360° angle-of-attack range. The results shown in figure 10(a) (effect of longitudinal shift of the center of gravity) indicate that the sphere-cone combination trims at a usable angle of attack only when the center of gravity is located very near the center of volume (i.e., closer than about 15 percent of the body length). For other center-of-gravity locations, the trim angle is either 0° or 180° and, as a result, no lift would be produced. With the center of gravity located on the longitudinal axis and near the center of volume, the configuration has two stable trim points, one at a positive angle of attack and one at a negative angle of attack. However, the results shown in figure 10(b) (effect of transverse shift of the center of gravity) indicate that by locating the center of gravity off the longitudinal axis, the sphere-cone combination can be made to have only one stable trim point.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 31, 1961

A586

REFERENCE

1. Grimminger, G., Williams, E. P., and Young, G. B. W.: Lift on Inclined Bodies of Revolution in Hypersonic Flow. Jour. Aero. Sci., vol. 17, no. 11, Nov. 1950, pp. 675-690.

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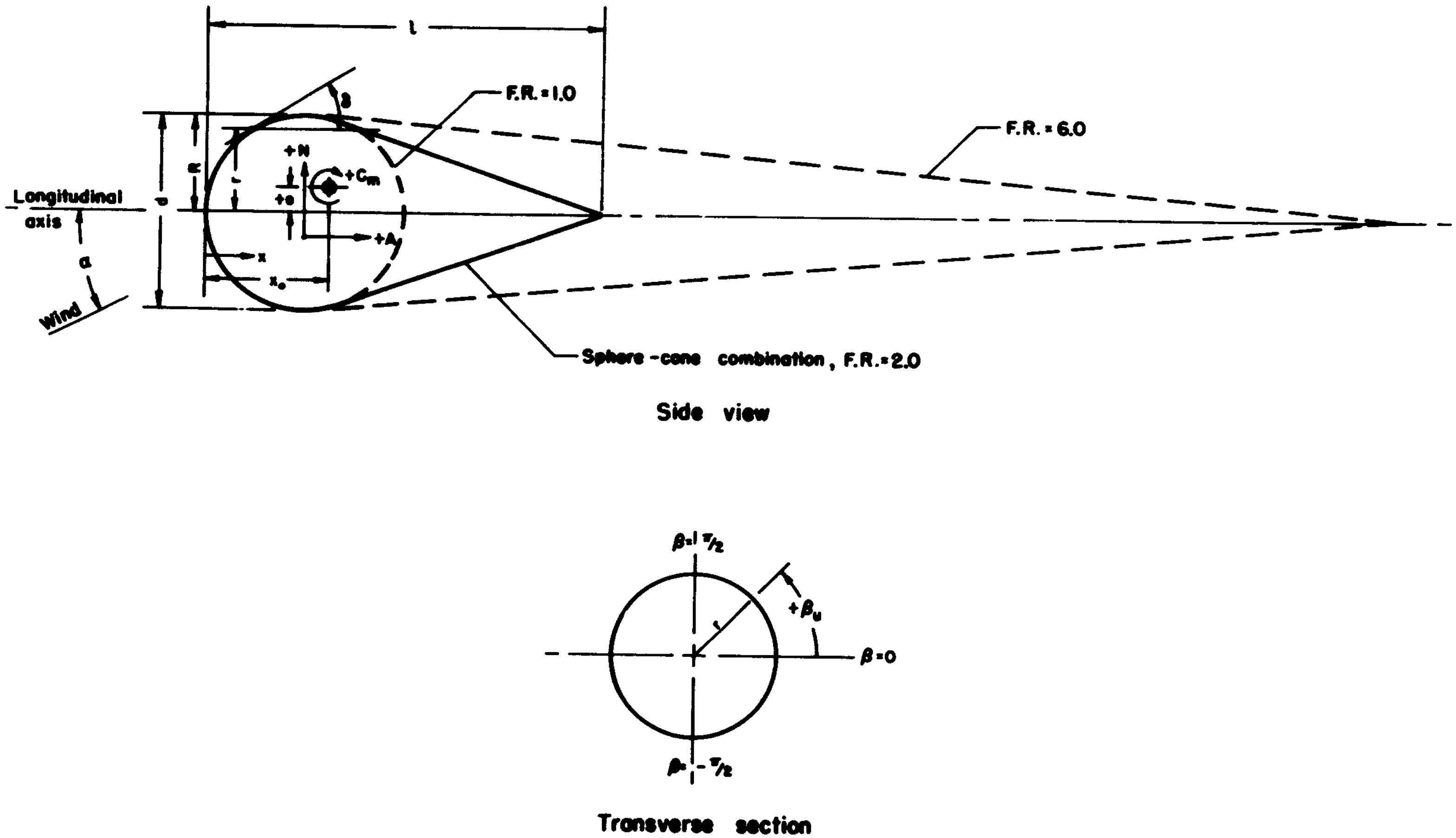

Figure 1.- Geometry of sphere-cone combinations.

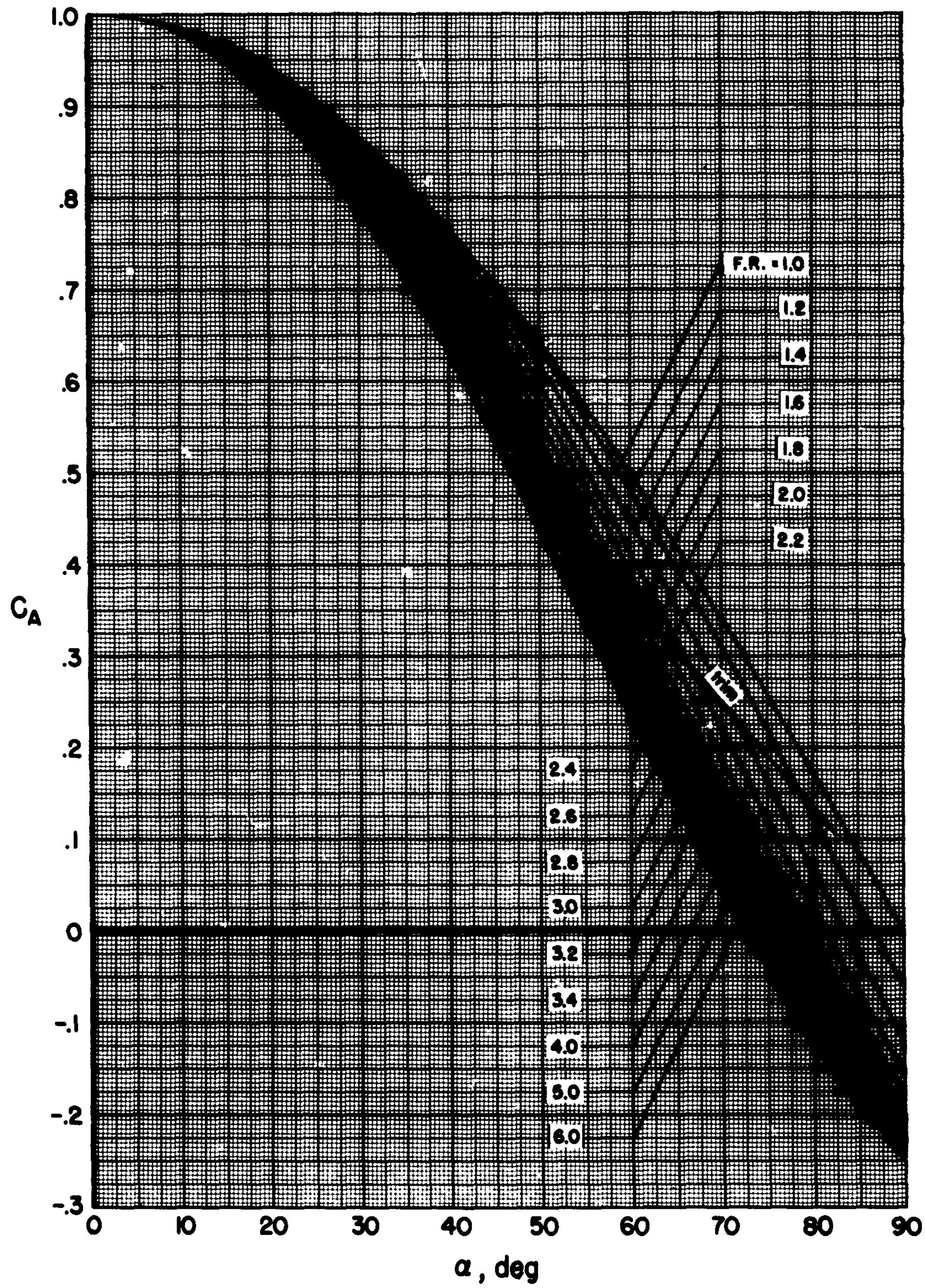

Figure 2.- Axial-force coefficients of sphere-cone combinations.

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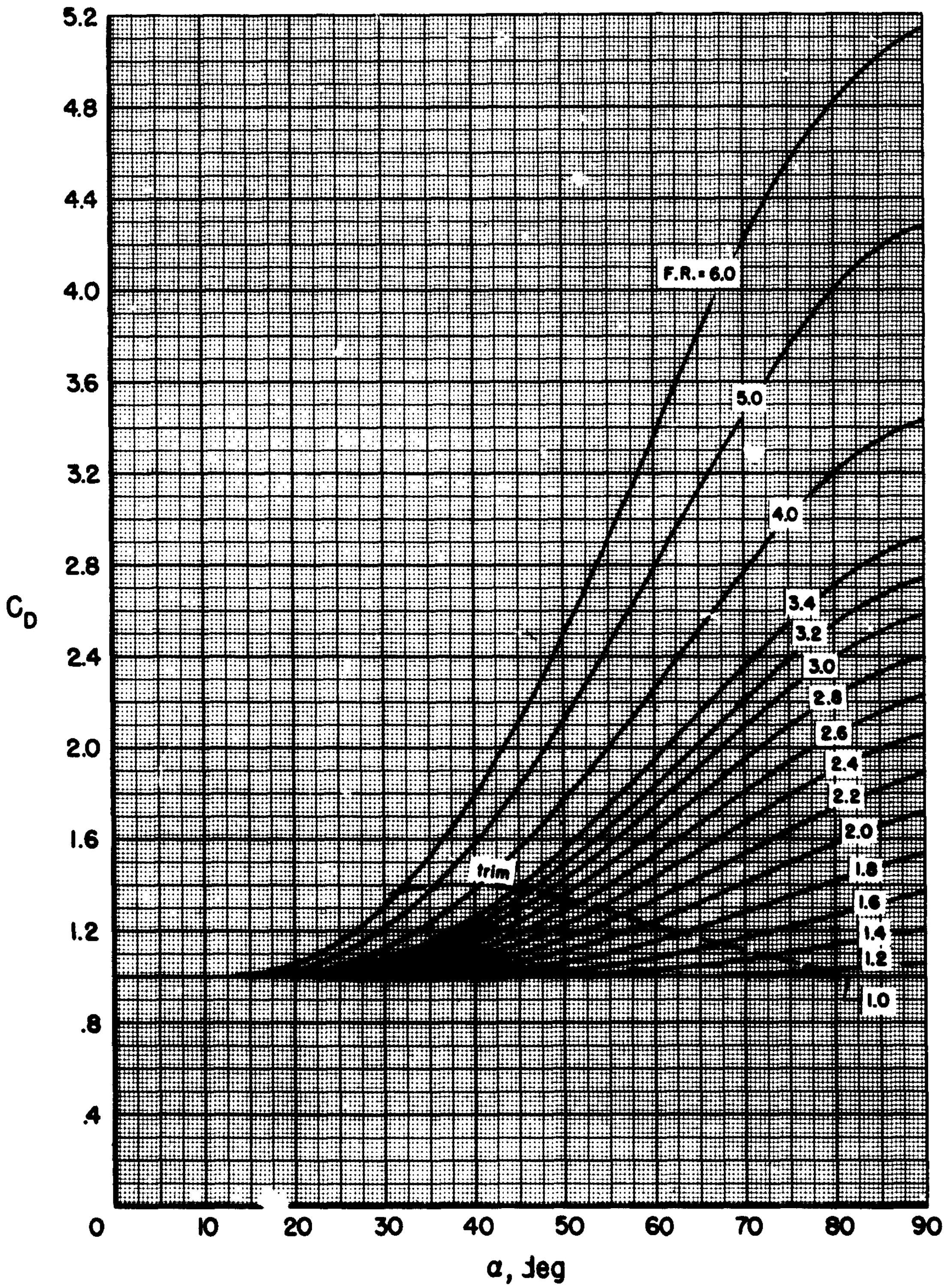

Figure 3.- Drag coefficients of sphere-cone combinations.

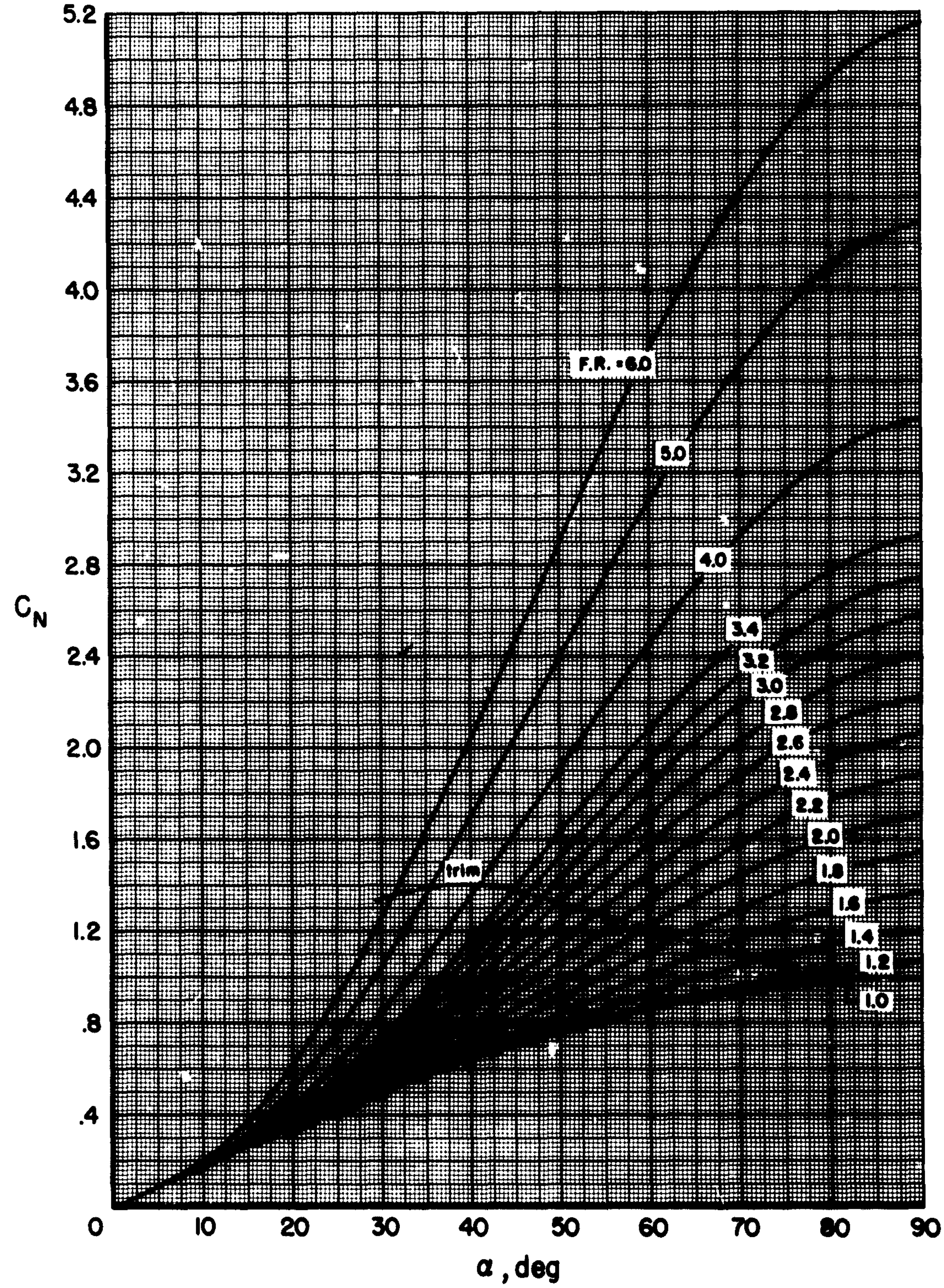

Figure 4.- Normal-force coefficients of sphere-cone combinations.

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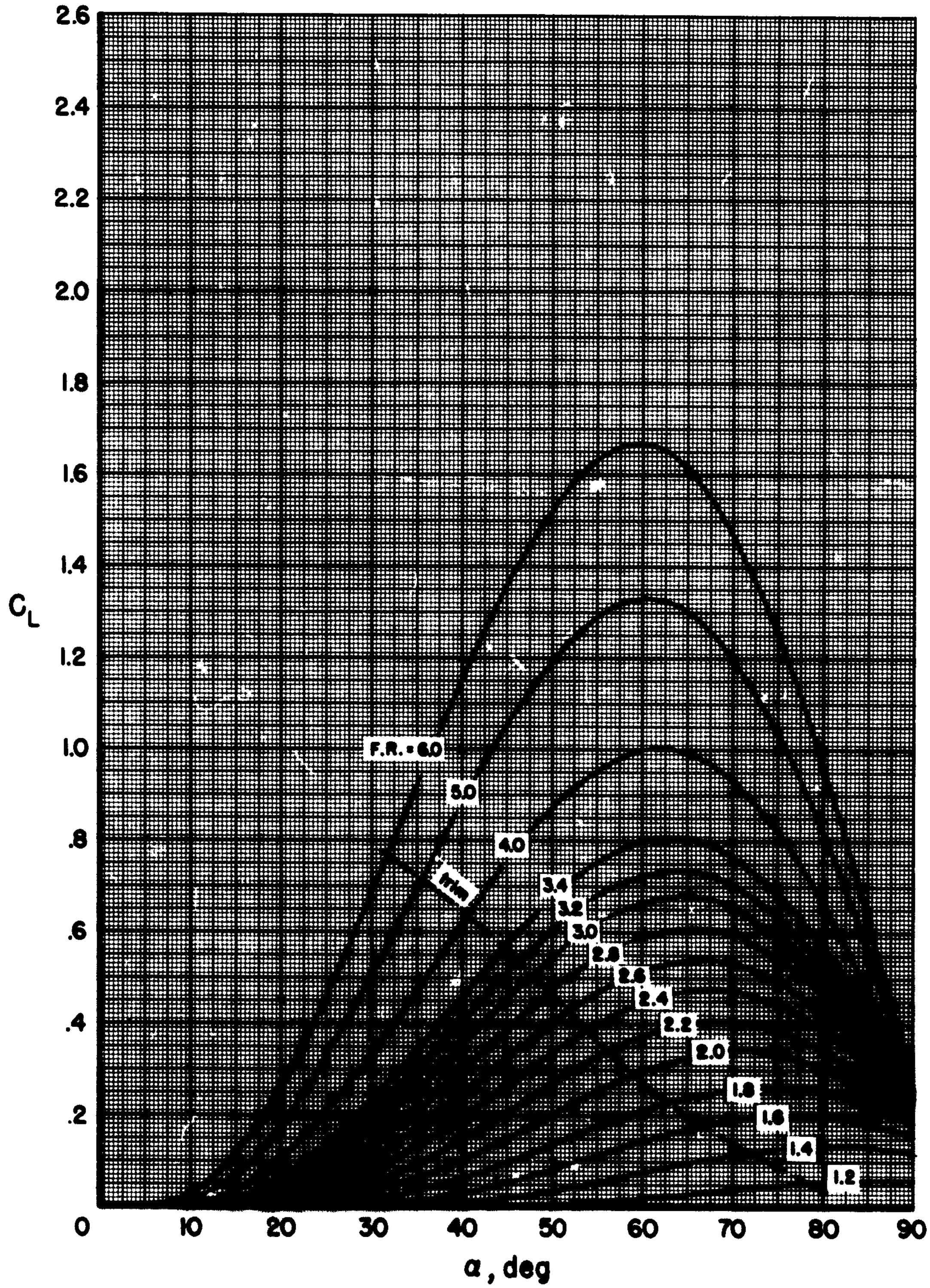

Figure 5.- Lift coefficients of sphere-cone combinations.

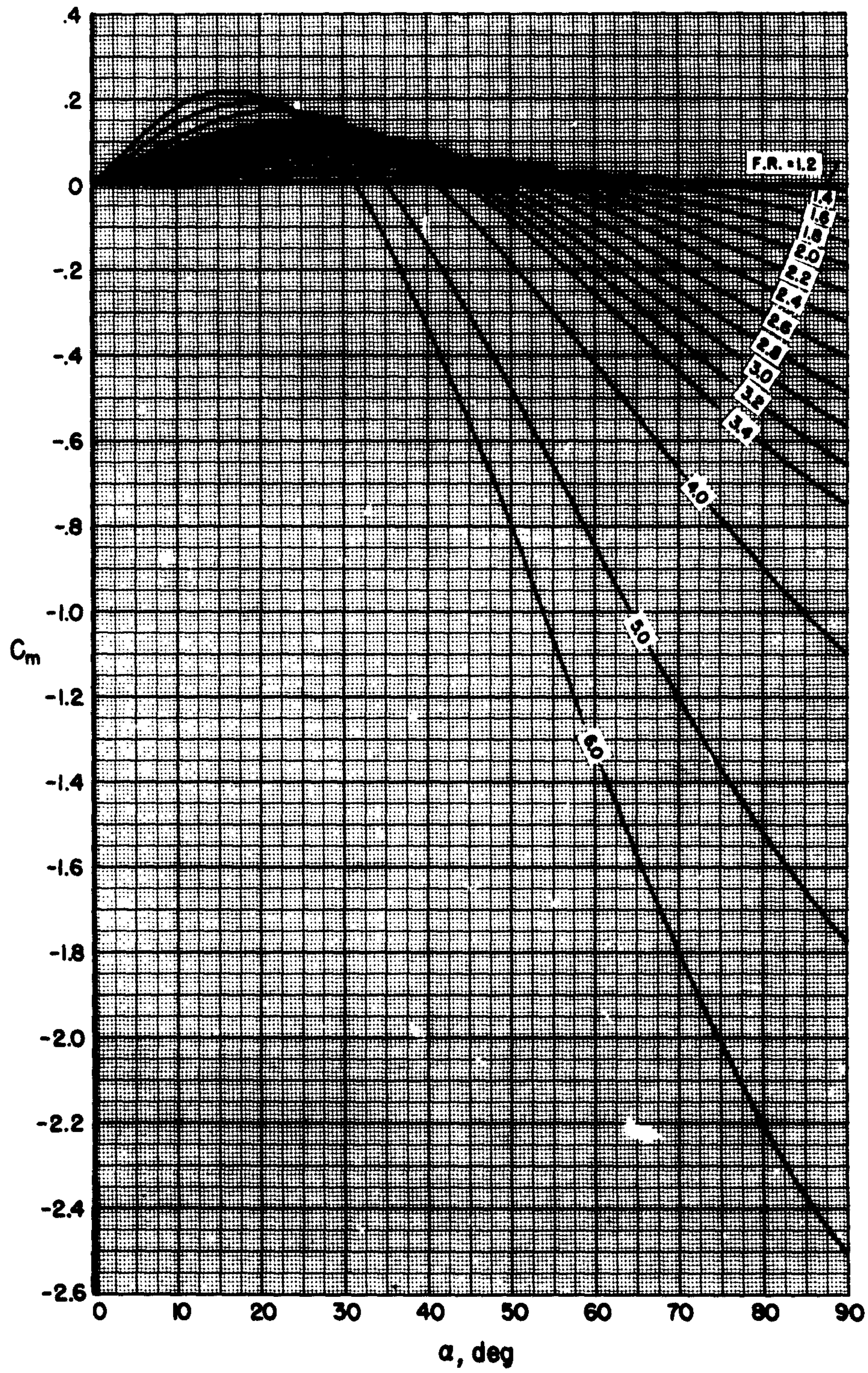

Figure 6.- Pitching-moment coefficients of sphere-cone combinations with center of gravity at the center of volume.

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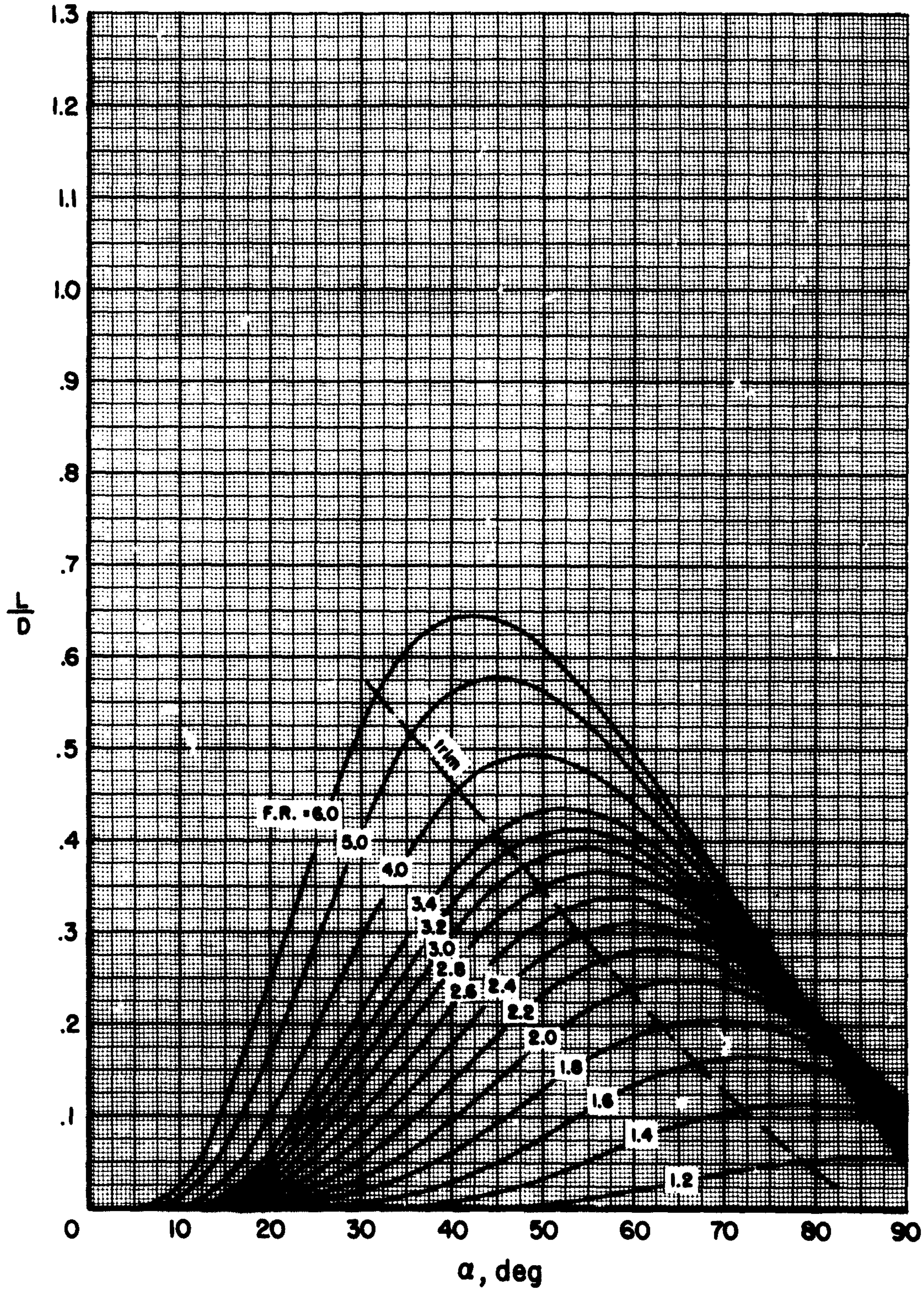

Figure 7.- Lift-drag ratios of sphere-cone combinations.

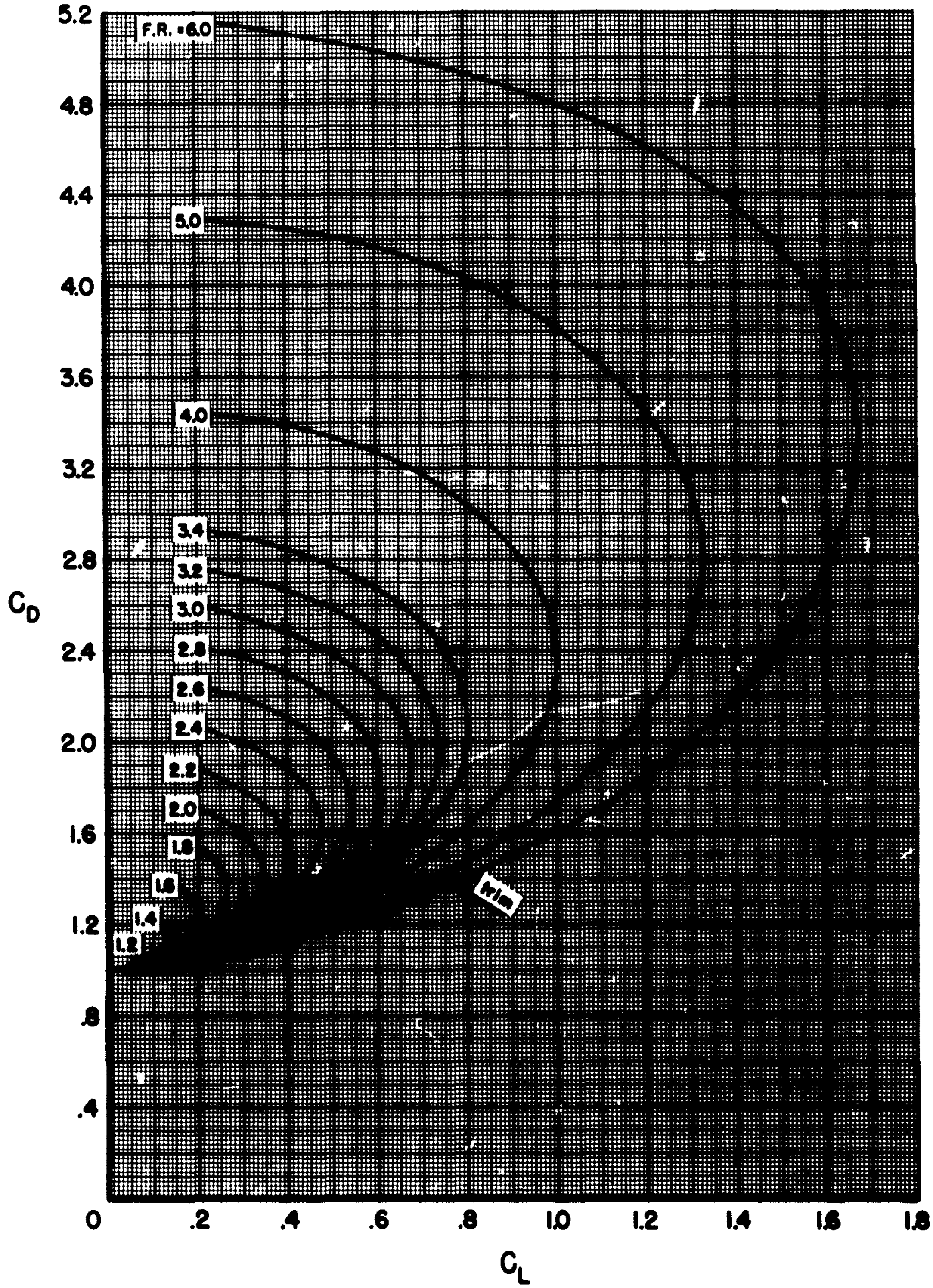

Figure 8.- Drag polars of sphere-cone combinations.

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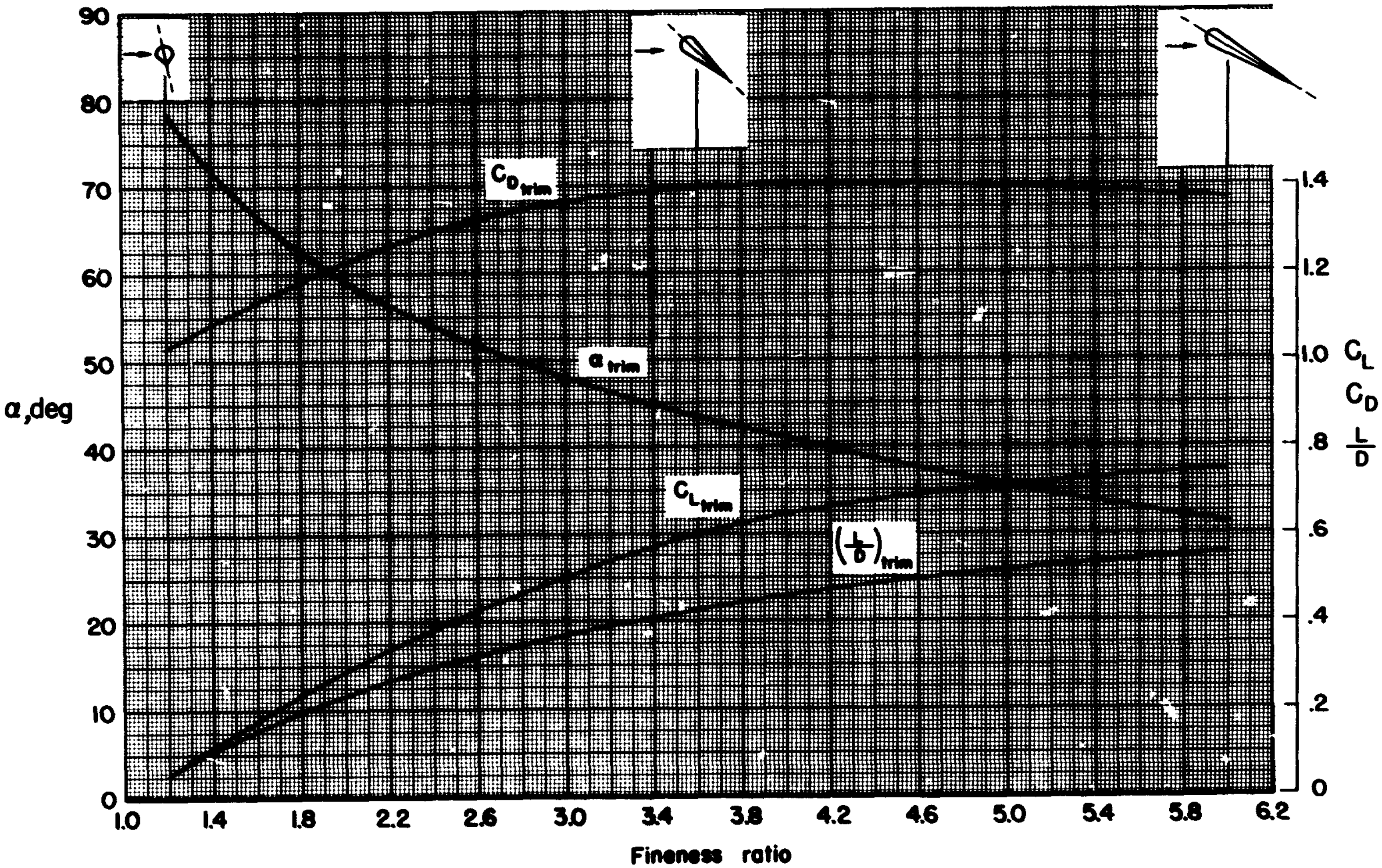
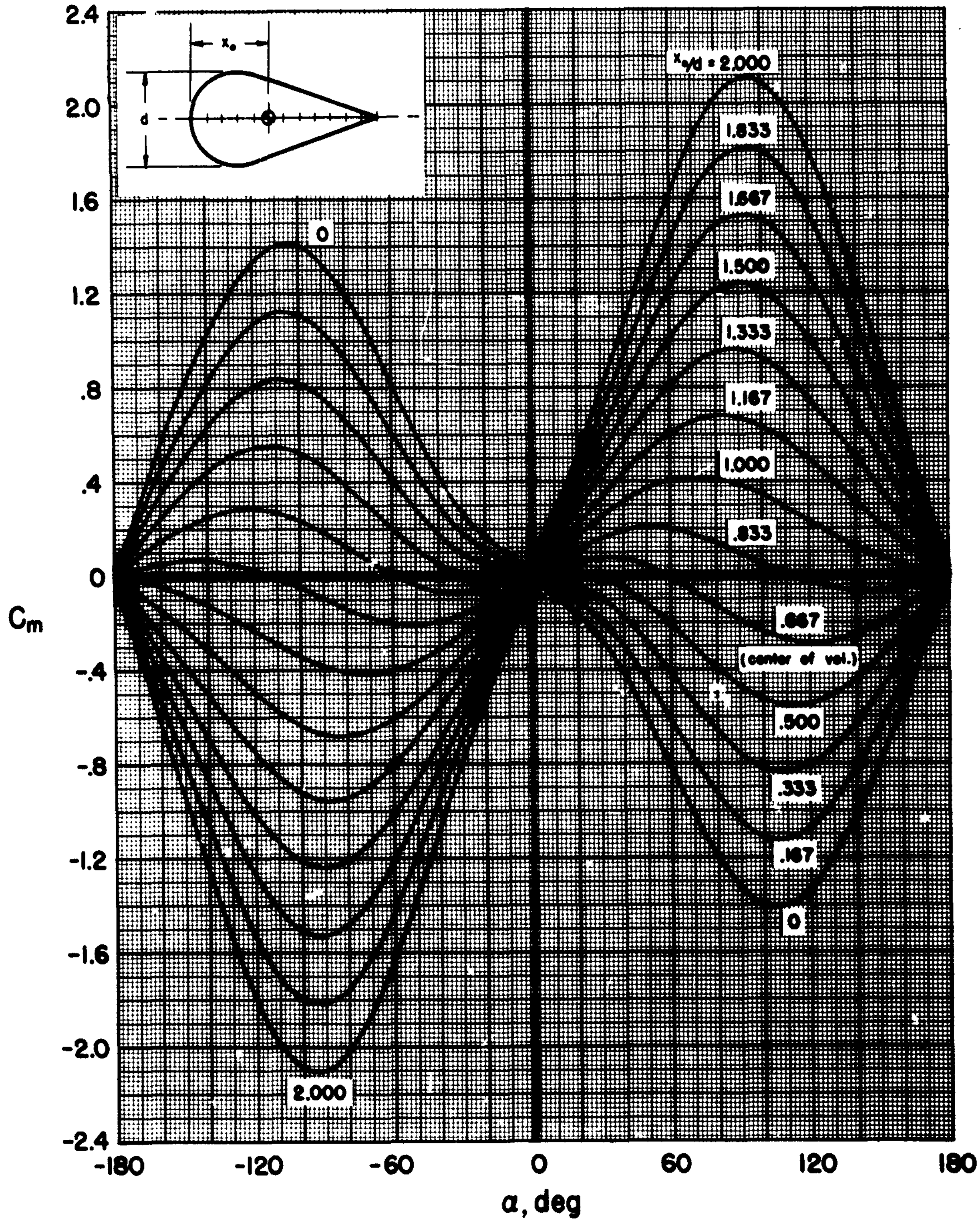


Figure 9.- Aerodynamic characteristics of sphere-cone combinations at trim with center of gravity at the center of volume.



(a) Longitudinal shift of center of gravity.

Figure 10.- Effect of center-of-gravity location on the pitching-moment coefficients of a sphere-cone combination of fineness-ratio 2.

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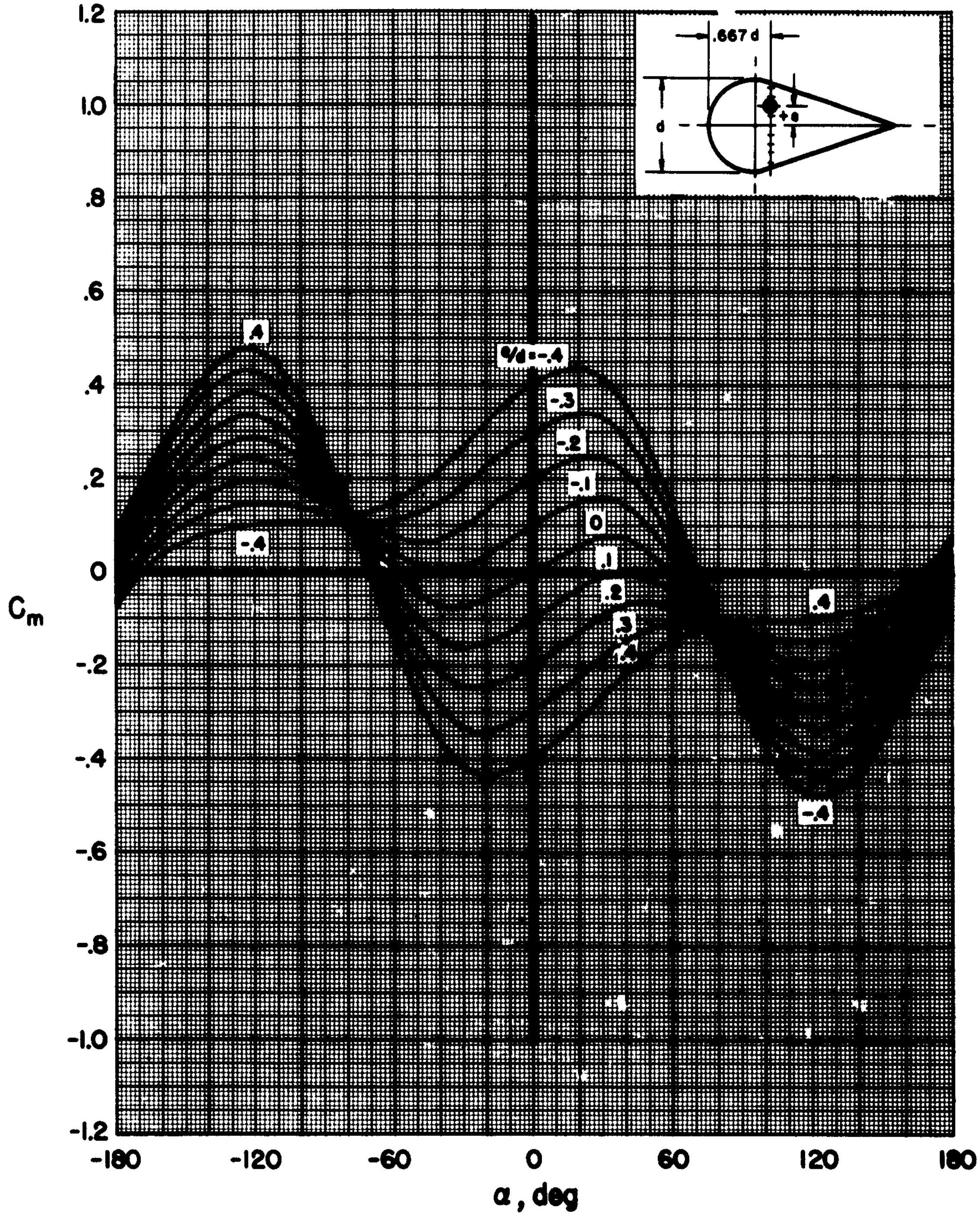

(b) Transverse shift of center of gravity from the center of volume

Figure 10.- Concluded.

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